

Laser Sounder Approach for Global Measurement of Tropospheric CO₂ Mixing Ratio from Space

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Abstract: We report progress in assessing the feasibility of a new satellite-based laser-sounding instrument to measure CO₂ and other trace gas abundances in the lower troposphere from space.

1. INTRODUCTION

CO₂ measurements from ice cores show that atmospheric CO₂ concentrations are higher now than they have been in the past 400,000 years. It is becoming increasingly important to understand the nature and processes of the CO₂ sinks, on a global scale, in order to make predictions of future atmospheric composition. Accurate measurements of tropospheric CO₂ abundance with global-coverage, 300 km spatial and monthly temporal resolution are needed to quantify processes that regulate CO₂ storage by the land and oceans [1].

The NASA Orbiting Carbon Observatory (OCO) is the first space mission focused on atmospheric CO₂ for measuring total column CO₂ and O₂ by detecting the spectral absorption in reflected sunlight. The OCO mission will yield important new information about atmospheric CO₂ distributions. However there are unavoidable limitations imposed by its measurement approach. These include best accuracy only during daytime at moderate to high sun angles, interference by cloud and aerosol scattering, and limited signal from CO₂ variability in the lower tropospheric CO₂ column. The recent NRC Decadal Survey for Earth Science [2] has recommended addressing these un-met needs in a laser-based CO₂ measuring mission called ASCENDS.

We have been in developing a laser technique for the remote measurement of the tropospheric CO₂ concentrations from orbit [3-6]. Our initial goal is to demonstrate a lidar technique and instrument technology that will permit measurements of the CO₂ column abundance in the lower troposphere from aircraft at the few ppm level. Our final goal is to develop a space instrument and mission approach for

active CO₂ measurements. This would allow continuous measurements of CO₂ mixing ratio from orbit, both day and night, over land and ocean surfaces, and under realistic atmospheric scattering conditions.

2. APPROACH

Previous and some ongoing efforts to develop laser instruments for measuring atmospheric CO₂ have used the 4.88 μ m [7] and 2 μ m [8-11] bands. Our approach is to use the 1570nm band and a dual channel laser absorption spectrometer (ie DIAL lidar used an altimeter mode), which continuously measures at nadir from a near polar circular orbit (Figure 1).

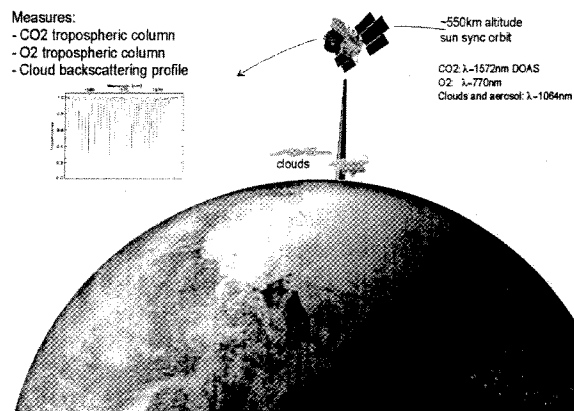


Figure 1- Measurement concept for space-based CO₂ Laser Sounder.

We use several tunable fiber laser transmitters allowing simultaneous measurement of the absorption from a CO₂ absorption line in the 1570 nm band [12], O₂ extinction in the oxygen A-band, and surface height and aerosol backscatter in the same

measurement path. The approach directs pulsed co-aligned laser beams from the instrument's lasers toward nadir, and measures the energy of the laser echoes reflected from land and water surfaces. During the measurement the lasers are stepped across a selected CO₂ line near 1572 nm and a pair of O₂ lines near 765 nm lines at kHz rates.

The lasers are a MOPA architecture using tunable diode seed lasers and fiber amplifiers, and have spectral widths much narrower than the gas absorption lines. The receiver uses a ~1.5-m diameter telescope and photon counting detectors [13], and measures the background light and energies of the laser echoes from the surface along with scattering from any clouds and aerosols in the path. The gas extinction and column densities for the CO₂ and O₂ gases are estimated from the ratio of the on- and off-line signals via the differential optical absorption technique. Pulsed laser signals and time gating are used to isolate the laser echo signals from the surface, and to exclude photons scattered from clouds and atmospheric aerosols.

The 1570 nm CO₂ band [13] shown in Figure 2 is well suited for this measurement. It is largely free from interference, has absorption lines with the needed temperature insensitivity and strengths [14], and is within the spectral range of high power lasers and sensitive photon counting detectors.

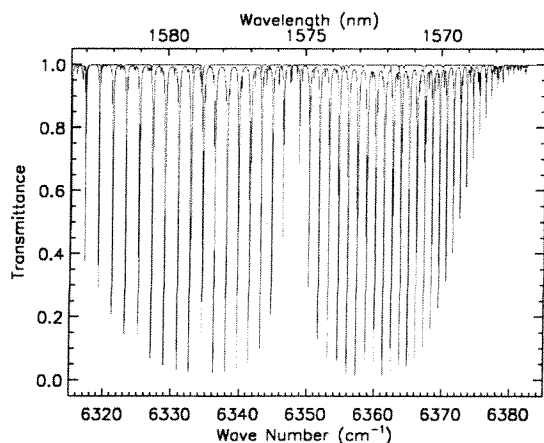


Figure 2 – 2-way atmospheric absorption from space for the 1570 nm CO₂ band (from HITRAN).

Our technique uses the on-line wavelengths tuned to the sides of the gas absorption line. This exploits the atmospheric pressure broadening of the gas lines to weight the measurement sensitivity to the atmospheric column below 5 km. This maximizes

sensitivity to CO₂ changes in the boundary layer where variations caused by surface sources and sinks are largest. Simultaneous measurements of total pressure use a pair of lines in the Oxygen A-band near 765 nm. Laser altimetry and atmospheric backscatter profiles are also measured simultaneously, which permits determining the surface height and measurements made to cloud tops and through aerosol layers.

The laser sounder approach has some fundamental advantages over measurements with passive sensors using reflected sunlight. It measures gas absorption in a common nadir/zenith path and the narrow laser divergence produces small laser footprints. The laser sources allow measurements in sunlight and darkness allowing global coverage. It can measure continuously over the ocean, to cloud tops and through broken clouds. The lasers are pulsed and potential measurement errors from scattering from clouds and aerosols are greatly reduced by using time gating in the receiver. Nonetheless, the optical absorption change due to a few ppm change in CO₂ is quite small, <1%, which makes achieving measurement sensitivity and stabilities challenging. Signal-to-noise ratios and measurement stabilities of > 700:1 are needed to allow CO₂ mixing ratio estimates at the few ppm level.

We have calculated several characteristics of the technique, and have demonstrated key aspects of the laser, detector and receiver approaches in the laboratory. We have also measured O₂ over a 206 m long path and CO₂ over 206m, 400m, 1.3 and 2.2 km long open horizontal paths [6] using a breadboard version of the sensor (Figures 3-5).

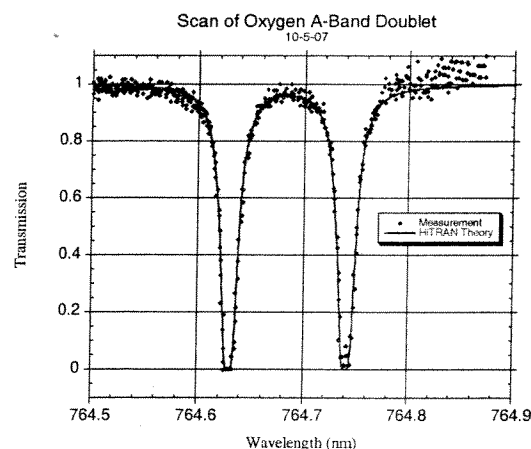


Figure 3 – Measurements of O₂ line pair using breadboard O₂ sensor in van over 220 m horizontal path compared to calculated line shapes from HITRAN.

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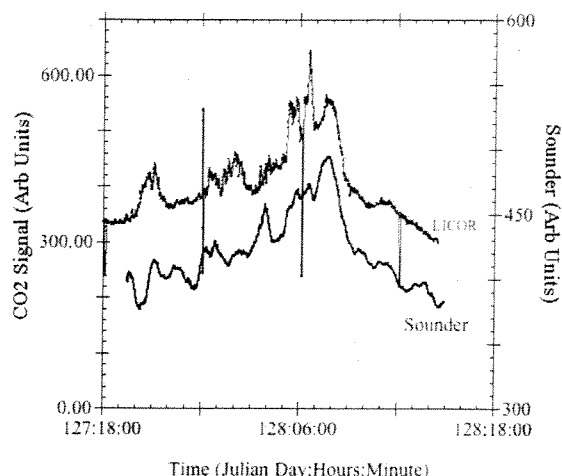


Figure 4 – Measured series of CO₂ absorption from with breadboard sensor from lab over 405 m horizontal path over 24 hr time span in May 2007 compared to end-point CO₂ measurements made at top of laboratory building.

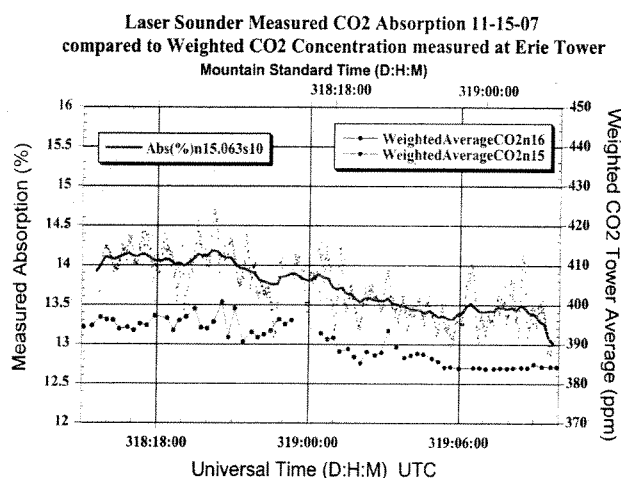


Figure 5 – Preliminary analysis of CO₂ absorption measurements made using breadboard sensor in van over 1.3 km slant path to side of NOAA CO₂ tower in Erie CO, compared to estimate from in-situ readings from tower. Measurement date was 11-15-07.

We will describe more details of the approach and our measurements in the talk.

3. ACKNOWLEDGEMENTS

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